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Optimal microclimatic control strategy using wireless sensor network and mobile measuring agent

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Abstract: Wireless Sensor Network technology can contribute in control strategy, productivity and quality of production through applications in controlled microclimatic environment. This work attempts to establish a pioneer agricultural environment and improve the productivity of crops by suggesting a using WSN technology. The proposed system can collect and monitor climatic parameters related to the microclimatic environment of crops outside and inside the system by applying WSN sensors. One of the main goals of the project is to develop a stabilized universal microclimatic environment control system which is capable for fast adaptive control in various conditions. The research area inside the controlled microclimatic environment is a wirelessly controlled mobile measuring station. The control surface is generally made with LabVIEW using the features of Microsoft SQL. Navigation of the mobile measuring robot can be done manually, relying on the visual data from the robot's camera, or can be switched to automatic mode where the developed algorithm is doing the navigation job. Mobile robot navigation is based on potential field method in combination of RSSI parameter of WSN considering a wide range of energy-aware parameters.
Key words: Mobile robot, WSN, Measuring agent, LabVIEW

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Introduction

A similar project was developed also by other researchers (Dae-Heon Park et. al., 2011), they make it possible to collect information and control the greenhouse automatically on site or from a remote place through a web browser. The proposed system by (Maliappis, et. al., 2008) describes a system developed to introduce computer management into the cultivation process in low-tech greenhouses. A research paper presented by (Andrzej P. et. al., 2009) describes how the greenhouse climate control can be represented as an event-based system in combination with wireless sensor networks, where low-frequency dynamics variables have to be controlled and control actions are mainly calculated against events produced by external disturbances. Controlled microclimatic environmental conditions are used to grow plants for efficient production and forms an important part of the precision agriculture sector. Environmental monitoring systems have become an important part of a controlled microclimatic environment for optimum crop growth, efficient resource usage, and better utilization of the energy. Many researchers have been making attempts to develop their own controlled microclimatic environment, but fixed measuring point was applied. The existing controlled microclimatic environments are very costly, difficult to maintain and less appreciated by the technologically less skilled work-force (A. Nafarieh, et. al. 2008). In this work an attempt has been made to devise a mobile measuring robot with onboard sensors with WSN support to real time monitor the climatic parameters which, directly or indirectly, have a vital role in the growth of the crops. The developed system is simple, cost effective, and easily installable. The parameters which are being real time monitored and stored in a SQL database for further analysis are temperature, humidity, solar radiation, CO_2 concentration, pressure etc.

Materials and methods

The advantage of this system inside the controlled micro-climatic environment is fast and easy to setup. There is no need for sensor cablings which can decrease installation costs dramatically. Mounting the sensor nodes on an appropriate place is the main task during the installation. All the necessary programming and setup can be done over the wireless network (Erin-Ee-Lin Lau, et. al. 2008). When the installation of the sensor network is done, the mobile measuring station is ready to navigate along the crop rows from point A to point B collecting the environmental parameters.

WSN inside the controlled microclimatic environment

Considering the characteristics of the wireless sensor networks for the controlled microclimatic environment, the Cluster-based Structure design is chosen. In a cluster, a wireless sensor node can transmit data to the base station and transmit instructions to the control system (Gyula Mester, 2009). Only one base station exists in a controlled microclimatic environment. A typical cluster-based WSN for controlled microclimatic environment can be seen in Figure 1.

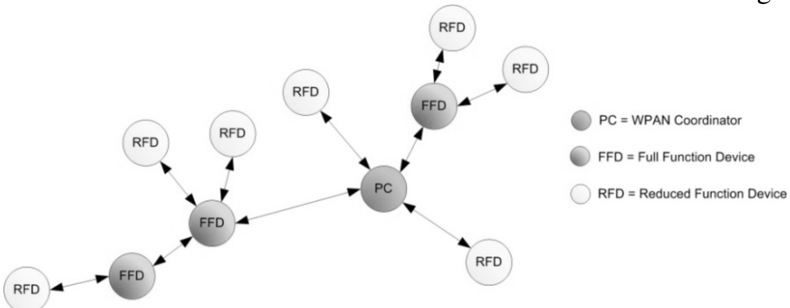

Figure 1. Cluster-based WSN for controlled microclimatic environment

Wireless sensor node's main job is to monitor and collect the entire controlled microclimatic environment's climate information. The task of the base station is to store and process the information that received from each sensor.

Mobile measuring robot inside the controlled microclimatic environment

The robot starts at the start point and its objective is to find an obstacle-free, continuous path from start to the target. This work aims to improve the performance of mobile robots in unknown environments. Several algorithms are simulated and investigated using the SunSPOT mote developing system (K. Yu, et. al. 2008). A model of measuring robot is given in Figure 2.

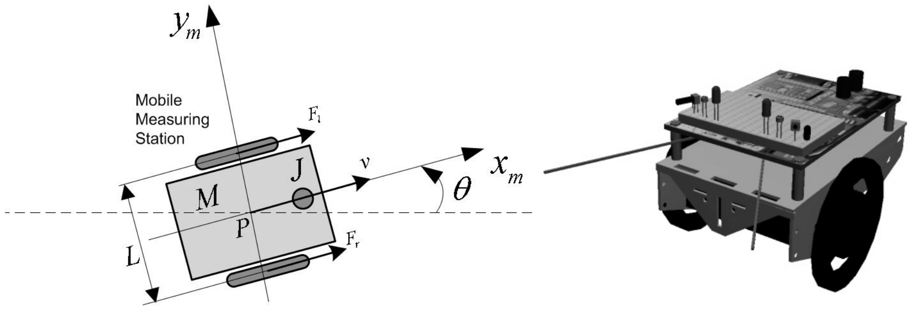

Figure 2. Mobile measuring robot

Radio Signal Strength Indicator (RSSI) based localization techniques are based on the fact that the strength of the radio signal fades during propagation (Simon J., et. al. 2009). As a result, the understanding of radio attenuation helps to map the signal strength to the physical distance. In theory, radio signal strengths fade with distance according to a power law. A generally employed model for wireless radio propagation is as follows:

$$P(d) = P(d_0) - \eta 10 \log\left(\frac{d}{d_0}\right) + X_\sigma \quad (1)$$

Where $P(d)$ is the received power at distance d, $P(d_0)$ the received power at some reference distance d_0, η the path-loss exponent, and X_σ a log-normal random variable with variance σ^2 that accounts for fading effects. Hence, if the path-loss exponent for a given environment is known, the received signal strength can be translated to the signal propagation distance.

Table 1. Estimated distance based on measured RSSI signal

RSSI Value [dDm]	-21	-24	-26	-36	-27	-41	-52	-44	-48	-48	-51	-47	-44	-41
Distance [m]	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4

RSSI Value [dDm]	-48	-50	-51	-56	-53	-52	-57	-58	-61	-63	-57	-62	-61	-63
Distance [m]	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8

As shown in Table 1, the relationship of RSSI values and distance is not a smooth relation. Since the multi-path interference, the measured values vary randomly. The RSSI measurements are mainly influenced by propagation, such as obstacles, multi-path propagation fading and motion people (Simon J., et. al. 2009). Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different time. Since the communication environment is complex, it induces unsteadiness of the signal (M. T. Maliappis, et. al. 2008). The RSSI-based location methods mainly depend on the path loss model that converts RSSI values into corresponding distances. The RSSI based localization is shown in Figure 3. The sensor nodes are marked with a unique number.

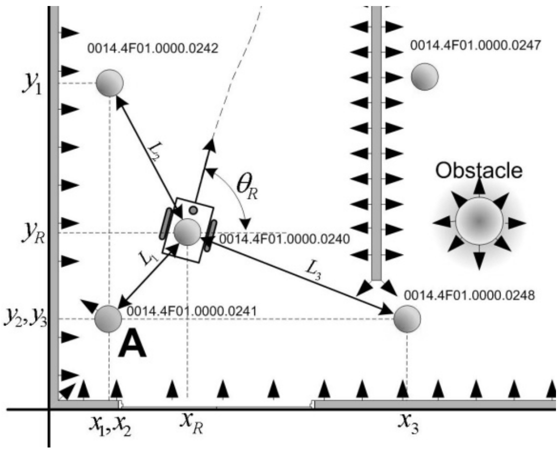

Figure 3. RSSI-based localization

RSSI-based ranging is a relatively cheap solution without any extra devices, as all network nodes are supposed to have radios. Combining RSSI localization with potential field method for obstacle avoidance (Khatib O., 1985) gives a good navigation result. The Hardware basically centers around Sun SPOT wireless node and DC Motors controlled by Basic Stamp. The Sun SPOT base station will send data to Sun SPOT on the mobile measuring station which will drive the Basic Stamp controller to DC IO pins (Matijevics I., et. al. 2009). The microcontroller will drive the Motors which will run the measuring station.

Real-time environmental control and monitoring

A LabVIEW application was developed to display the sensor data enabling users to interactively access the WSN data. Sensor data are uploaded from each node to a remote central server. The server side processes the incoming data and populates the SQL database (Martinović G. et. al., 2007). It allows live monitoring and visualization of climate, atmosphere, plants and soil data from the controlled microclimatic environment (Masashi Sugano, et. al. 2006). It also provides a dashboard for displaying sensor readings and derived parameters such as max temperature. The measurement process is depicted in Figure 4.

Figure 4. Measurement process

Historical data displayed in grid and graphical formats which can be customized to provide better visualization of logged data. Figure 5 shows LabVIEW monitoring application displaying the controlled microclimatic environmental data. Table 2 gives an overview of temperature parameters of various crops (Matarić, M. J., 2007).

In order to fully automate the controlled microclimatic environment climate control, a comprehensive supervisory system is designed to serve as a user-friendly interface with the operator (Pletl Sz., et. al. 2010). The developed system is analyzed and validated through simulation and a series of tests, giving adequate modeling to aspects that are of direct relevance.

Table 2. Temperature parameters for crops

Crop type	Optimal day temperature	Optimal night temperature	Minimal grow temperature	Damage from frost
Capsicum	25 C°	18 – 20 C°	12 C°	- 0,5 C°
Tomato	22 C°	14 – 18 C°	10 C°	- 0,5 C°
Strawberry	19 C°	8 – 10 C°	4 C°	- 5 do – 10 C°
Cucumber	16 C°	8 – 14 C°	5 C°	- 5C°

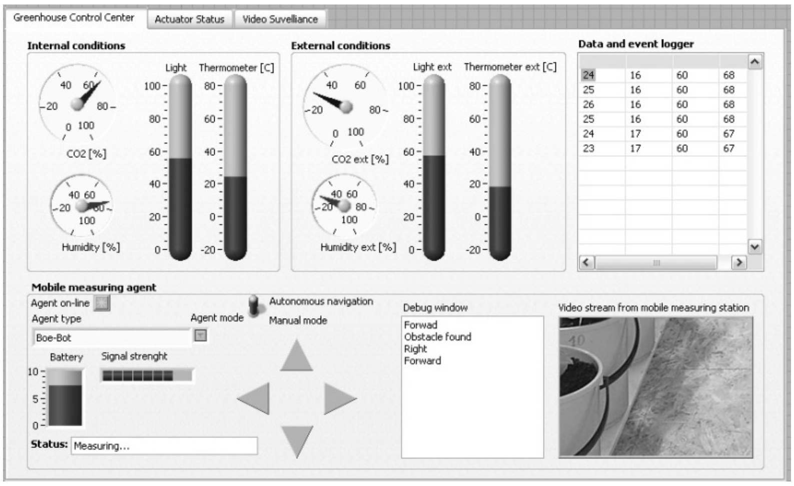

Figure 5. Control surface (LabVIEW)

Real-time sensor data collection is used for accurate illustrations of current conditions while forecasting future conditions and risks (Simon J., et. al. 2009). The real time information from the controlled microclimatic environment can provide a solid base for administrators to adjust strategies at any time. Instead of making decisions based in some hypothetical average condition, which may not exist anywhere in the reality, a precision agriculture approach recognizes differences and adjusts management actions accordingly (Stefano Tennina, et. al. 2008).

Results and Discussion

One of the goals of this project is to develop algorithms for coordination and navigation of the mobile measuring station inside the controlled microclimatic environment (Youngjune Gwon, et. al. 2004). When the sensor node has sampled data from its environment, a strategy is required to manage how the data is made available to other nodes, a central sink node, or the end-user. Also developing a controlled microclimatic environment test environment for real-time tests and analysis was done. Table 3 is the representation of raw data from the database.

Table 3. Collected data from sensors

Time	Temperature (°C)	Dew Point (°C)	Pressure (hPa)	Wind	Wind Speed (km/h)	Wind Gust (km/h)	Humidity (%)	Rainfall Rate - Hourly (mm)	Date
0:00	13.7	9.6	1008.0	ENE	3.2	4.8	76	0.0	3 may 2011
0:05	13.7	9.6	1008.0	East	3.2	4.8	76	0.0	3 may 2011
0:10	13.7	9.6	1008.0	East	3.2	4.8	76	0.0 mm	3 may 2011
0:15	13.6	9.4	1008.0	NE	1.6	4.8	76	0.0 mm	3 may 2011
0:20	13.7	9.7	1008.4	SW	1.6	4.8	77	0.0 mm	3 may 2011
0:25	13.6	9.8	1008.4	WSW	1.6		78	0.0 mm	3 may 2011

Figure 6 shows a graphical representation of collected temperature and humidity data stored in the database. Controlling the humidity in the microclimatic environment can increase crop production, benefits in disease reduction and improved growth (Babić M., et. al. 2005).

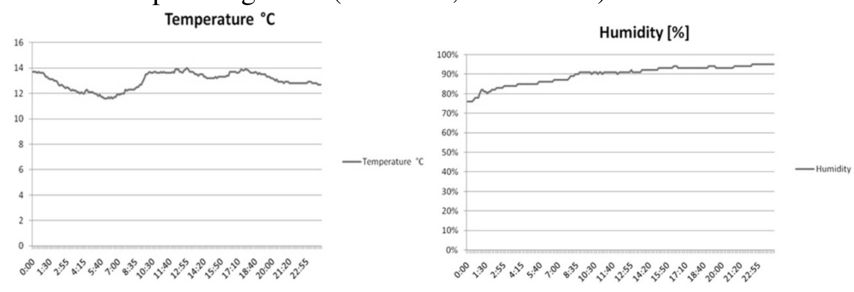

Figure 6. Graphs of measured data

The humidity control has a special interest, because high humidity may produce the appearance of diseases and decrease transpiration, and low humidity may cause hydric stress (Matijevics I., et. al. 2010). The intensity of solar radiation during one year in Subotica is depicted in Figure 7.

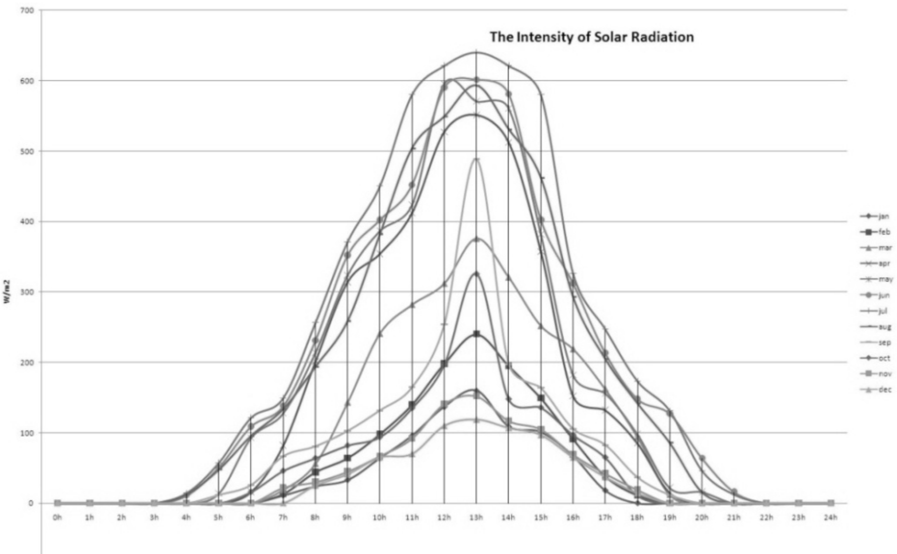

Figure 7. The intensity of solar radiation during one year in Subotica

Plants grow under the influence of the PAR radiation, performing the photosynthesis process. Furthermore, temperature influences the speed of sugar production by photosynthesis, and thus radiation and temperature have to be in balance in a way that a higher radiation level corresponds to a higher temperature (Andrzej P. et. al., 2009).

Conclusion

The environment monitoring system has been successfully implemented in compliance with the mobile measuring robot. The environmental sensors can be used to monitor the climatic parameters. The usage of the semiconductor sensors adds several advantages to a system such as low cost, fast response, low maintenance, user friendly and ability to produce real time measurements. A mobile measuring robot makes the system to be used for real time application. The implemented system is successful in measuring the temperature, humidity, solar radiation, and concentration of CO_2 gases. Initial results of the study are encouraging. But this has its own limitations, as these results are based on a small number of measurements. To increase the level of accuracy, the author and his associates are planning to conduct more measurements in different greenhouse environments. The information of the system can be easily exchanged between farmer and expert.

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Optimalna strategija kontrole mikroklime primenom mobilnog robota i BSM-A

- originalni naučni rad -

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Rezime

Cilj rada je projektovanje, implementacija i objedinjavanje hardverskih i softverskih komponenata razvojnog sistema za testiranje algoritama za navigaciju mobilne merne stanice unutar kontrolisane mikro-klimatske sredine u realnom vremenu. Istražuje se algoritam za navigaciju u dvodimenzionalnom prostoru sa podrškom za BSM. Algoritmi koji izvršavaju ovakav zadatak, nazivaju se navigacijski algoritmi. Postojeće metode potencijalnih polja su poboljšane i prilagođene zadatim uslovima i njegove performanse su merene i analizirane. Upravljanje kretanja mobilnih robota je danas veoma atraktivna istraživačka oblast kako iz aspekta teorijskih istraživanja tako i iz aspekta praktične primene. Kontrolna površina mikro-klimatske sredine je urađena u LabVIEW okruženju kao i prikupljanje izmerenih vrednosti. Istraživanje se bazira na autonomno upravljanje mobilnih robota na točkovima pri kretanju u nepoznatom okruženju sa preprekama. U radu objekat upravljanja je mobilni robot Boe-Bot od Parallaxa.

Ključne reči: BSM, Mobilni robot, LabView